

Tectonomagnetic effects

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ABSTRACT

Expected geomagnetic effects associated with earthquakes have amplitudes of a few gammas and derive from stress modification of the magnetocrystalline anisotropy of magnetic minerals in rock. A number of detection programs and control experiments throughout the world have yielded promising results but no clear observation of these effects. An array of 120 temporary and seven permanent differential magnetometer sites are installed in seismic areas in the western United States. Broad-scale time-dependent magnetic anomalies occur in areas where the seismicity is greatest.

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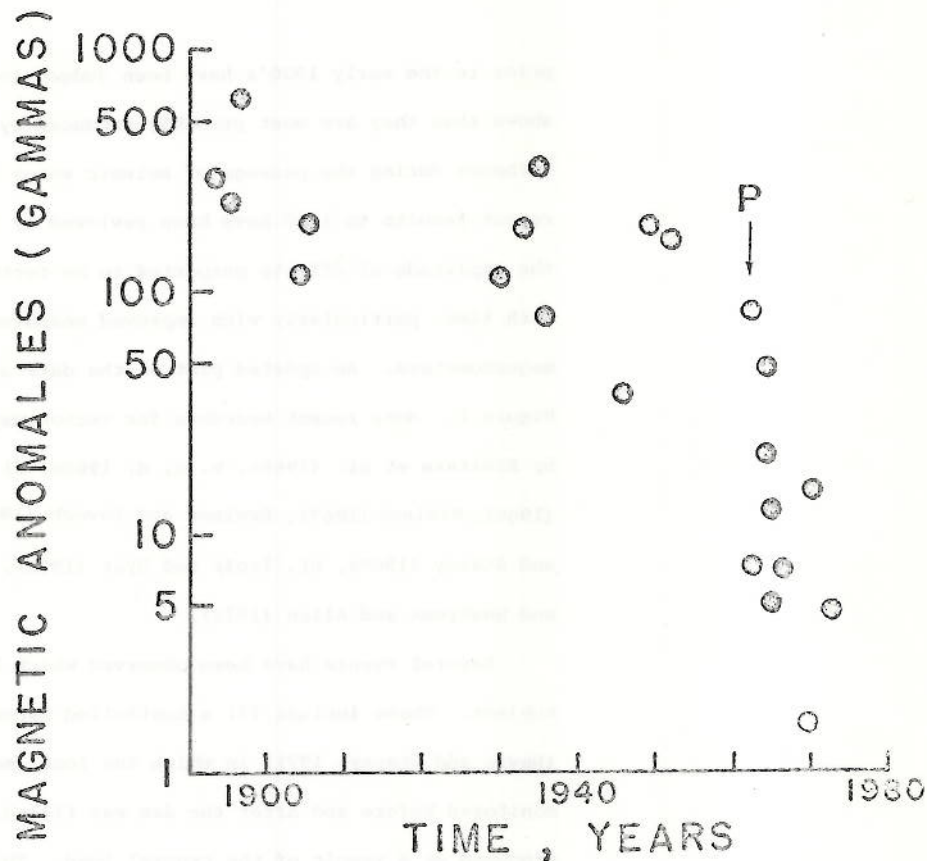


Fig. 1. Reported tectonomagnetic anomalies as a function of time (updated from Rikitake, 1968) P marks the introduction of drift free magnetometers.

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permanent local magnetic field change that occurred at the time of the Cannikan nuclear blast on Amchitka Island (Hasbrouck and Allen, 1972). These effects were more than 7 gammas. However in this case it is difficult to separate shock magnetization of the rocks at the time of the blast from piezomagnetic effects; (5) the observations at Matsushiro of a 10 gamma increase over ten months prior to the end of an earthquake swarm and a change of a few gammas that occurred at the time of the peak seismic activity (Rikitake et al. (1966a, b, c) Yamazaki and Rikitake, 1970); (6) the observation of broad scale local magnetic anomalies associated with seismic activity on the San Andreas and other active faults in western United States (Johnston et al., 1973).

In this paper we will firstly, comment briefly on the physical basis of the piezomagnetic effect and the subsequent calculation of tectonomagnetic effects based on the relation between stress and both the induced and remanent magnetization, secondly, discuss active detection programs around the world and, in particular, the program that is now in operation in California to verify or refute these effects, and finally, show some of the results and discuss some of the problems we have encountered.

Physical basis of the piezomagnetic effect

The titanomagnetites $[x\text{Fe}_{21}\text{O}_4(1-x)\text{Fe}_3\text{O}_4]$ are the most common magnetic minerals in basalt and discussion of the stress sensitivity of remanent susceptibility must relate to these minerals. Rocks containing grains of magnetic minerals exhibit a domain structure that is sensitive to stress, shape, temperature, and magnetic fields. The application of a stress to such a material introduces a magnetic anisotropy of piezomagnetic origin by modification of the magnetocrystalline anisotropy and hence the response of the

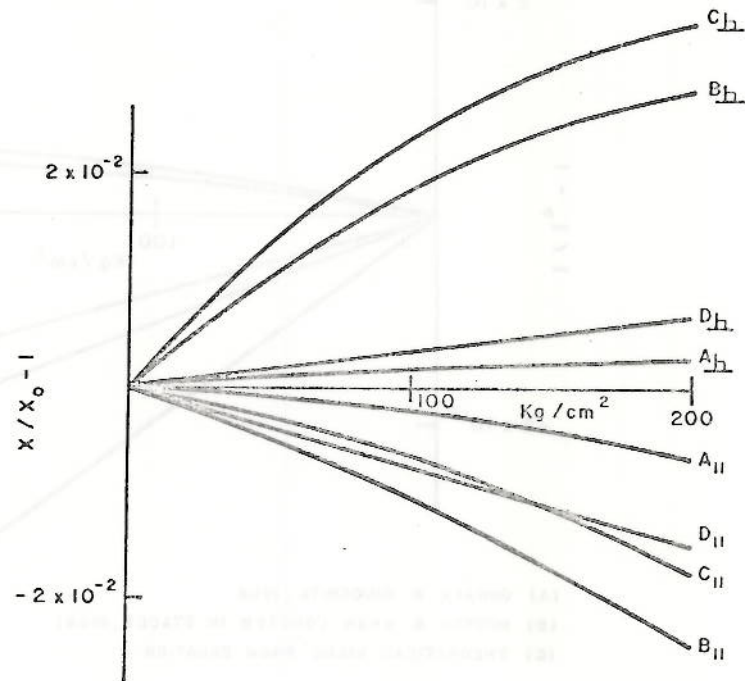
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(A) DIABASE
(B) ANDESITE (AFTER KALASHNIKOV & KAPITSA, 1952)
(C) BASALT
(D) THEORETICAL VALUE FROM EQUATION 1

Fig. 2a. The observed and calculated effect of stress on susceptibility both parallel and perpendicular to the stress direction.

A number of calculations of expected tectonomagnetic anomalies for typical fault models have been made. The most notable of these have been made by Stacey (1964), Stacey, Barr, and Robson (1965), Yukutake and Tachinaka (1966), Shamsi and Stacey (1968), and Talwani and Kovach (1971). Because of the heterogeneity of both rock properties and the likely stress fields, these models can at best provide only crude estimates of the amplitude (order of a few gammas) and spatial extent of such anomalies.

An order of magnitude calculation of tectonomagnetic effects can be made by representing the stressed region by a uniaxially stressed spherical volume of rock lying beneath the surface. The resulting change in magnetization gives rise to a surface field change which is equivalent to that of a buried dipole at the center of the sphere. Taking average values of magnetization and stress sensitivity of crustal rock as 10^{-3} e.m.u. and $2 \times 10^{-3} \text{ cm}^2/\text{kgm}$ respectively for an axial stress of 50 bars (taken as representative of tectonic stresses), field changes of 10-20 gammas will occur at the surface above the volume. The larger value corresponds to change in the vertical field component and the lower value to change in the horizontal component. This range agrees well with the Japanese, New Zealand, and Russian observations in which changes of 35, 40, and 23 gammas respectively were registered. In more detailed calculations surface anomaly fields were obtained by integration of the perturbation field from elemental magnetization change through the stressed region. Calculations by Rikitake (1968a), Yukutake and Tachinaka (1967), and Shamsi and Stacey (1969) and Talwani and Kovach (1972), differ only in details of the assumed stress distributions. All agree that effects between 1 gamma and 100 gammas should be observed in areas in which tectonic stresses of the order of 100 bars occur.

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However, the reliability of these instruments at less than 1 gamma sensitivity and in typical field conditions is yet to be proven.

Serious detection programs have been set up in Japan, New Guinea, Turkey, China, U.S.S.R. and U.S.A. with few results. The extremely high background noise in Japan appears to have put that program in jeopardy. The program in the United States of America has been concentrated in the seismic region in the western states. The general region is shown in Figure 3 which shows earthquakes larger than magnitude 5 for the past 40 years and the active faults.

Since the most critical problems in detecting tectonomagnetic effects in this and other regions are firstly to obtain clear and unambiguous observations, and secondly, to monitor large regions in the active seismic zones quickly and cheaply, we chose to use total field proton magnetometers with a resolution of a quarter gamma in a detection program. The first stage of this program has been to search for broad-scale long-period effects with a pair of magnetometers operated synchronously in a "leap-frog" survey mode. Data have been obtained at more than 120 pairs of sites along 1,200 km of the most active faults in California and Nevada. Over a twelve-month period, most sections have been resurveyed at least twice with some sections up to five times. The location of these sites is shown on Figure 4. The areas of most interest are where the magnetizations of the rocks are high, as indicated by surface observations and aeromagnetic maps and also where crustal stress is concentrated and perhaps increasing. Such areas are perhaps near San Juan Bautista (36°48'N, 121°32'W), Bear Valley (36°35'N, 121°12'N), Chalome (35°50'N, 120°20'W) Garlock (35°15'N, 117°45'W) and the Excelsior Mountains (38°20'N, 118°15'W) in Nevada. At each pair of adjacent sites, a set of about 75 total field values are recorded in a ten-minute period. The magnetometers are synchronized

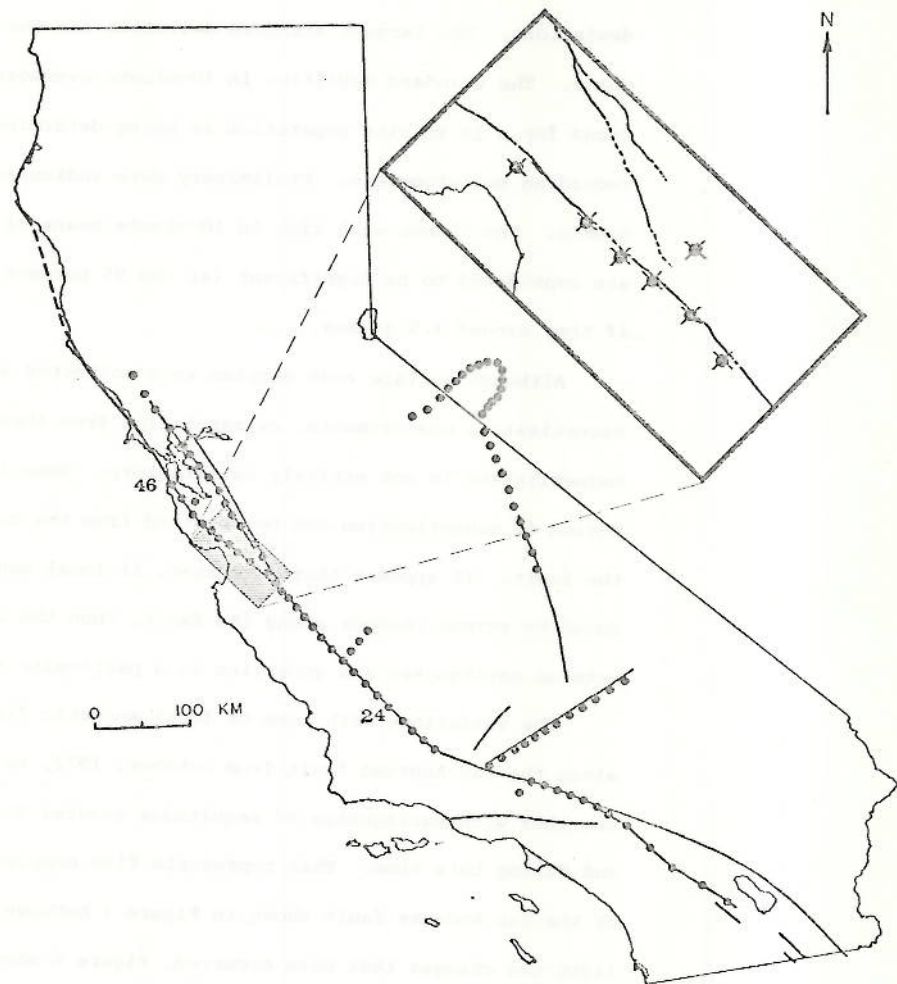
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TEMPORARY AND PERMANENT MAGNETOMETER SITES IN CALIFORNIA



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Fig. 4 Location of temporary (dots) and permanent (crossed dots) magnetometer sites in California and Nevada.

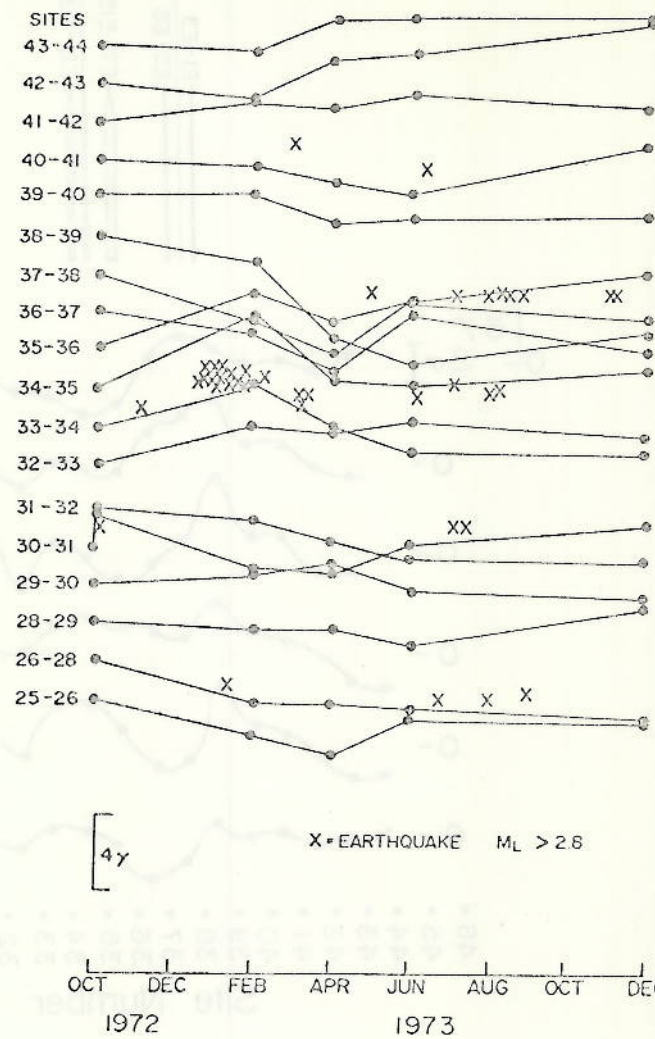


Fig. 5 Local magnetic field change with time between sites along 250 km of the San Andreas fault. The approximate location and occurrence time of earthquakes with magnitudes greater than 2.8 are marked with crosses.